ON THE

TEMPERATURE OF THE EARTH AND SEA,

IN REFERENCE TO

THE THEORY OF CENTRAL HEAT:

A Lecture,

DELIVERED AT THE ROYAL INSTITUTION, FEBRUARY 20TH, 1846,

LORD DE MAULEY, V.P. IN THE CHAIR,

BY

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MAN, AS THE MINISTER AND INTERPRETER OF NATURE, IS LIMITED IN ACT AND UNDERSTANDING BY HIS OBSERVATION OF THE ORDER OF NATURE; NEITHER HIS KNOWLEDGE NOR HIS POWER EXTENDS FARTHER."—BACON.

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ON THE

TEMPERATURE OF THE EARTH AND SEA.

AMONG the questions to which men of science have directed their attention in modern times, there is probably none which has excited greater interest than that which relates to the temperature of the globe. The physical geographer confines himself chiefly to the examination of the surface of the earth,—of the circumstances which affect the temperature of climates,—the relative distribution of land and water, the heights of mountains,—zones of vegetation, and subjects of the like nature. The researches of the geologist are directed to the determination of the nature and the order of superposition of strata, and the classification and arrangement of the fossil remains of an antediluvian world. Thus far physical geography and geology are sciences based upon an extensive series of well-ascertained facts. But when we attempt to determine the temperature and composition of the great mass of the globe, facts fail us—we are placed in uncertainty—an impassable barrier appears to be set before us, and conjecture takes the place of observation, Owing to this, men of the greatest eminence as philosophers and mathematicians have come to widely different conclusions with the same data before them. Thus, while one concludes that we are living upon the surface of a sphere, filled with melted matter, another argues that this

sphere is hollow—that, in short, the earth is a mere shell; and a third, that the nucleus of the globe is solid, and that it is gradually cooling down to the temperature of space.

It is not my intention to occupy your time in discussing the ingenious arguments which have been adduced in support of these conflicting views; but rather to direct your attention to certain well-ascertained facts, and leave you to draw your own conclusions respecting them.

I am aware that some of those whom I now have the honour of addressing, are well acquainted with the details into which I am about to enter; but I would here beg to observe, that in bringing forward this subject for a lecture before the members of the Royal Institution, my view has been, not so much to seek for novelty, as to combine in a slight general sketch some well-ascertained facts.

It is well known from the results of numerous experiments, and from astronomical observations, that the EARTH has the *form* of an oblate spheroid, or of a sphere somewhat flattened at the poles. Its greatest diameter may be taken, in round numbers, at about 8000 miles. The difference between the polar and equatorial diameters is about 26 miles—the polar diameter being the the lesser of the two. This difference is about equal to the 1-306th part of the earth's diameter, or, the polar axis being 305, the equatorial axis is 306. In a globe of 36 inches in diameter, the difference in the polar axis would, therefore, be (36 ÷ 306) nearly 0·12 inch, or about one-eighth of an inch, a quantity not perceptible to the eye.

The earth is surrounded by an *atmosphere*, a mixture of gases, or an aërial ocean, extending to a distance of 45 miles from the surface. This distance is partly calculated from the known laws of the refraction of light, and from the progressive decrease in the density of air by elevation. At 45 miles above the level of the sea, the air has only 1-12000th part of the density which it has upon the surface; and as this is equal to a good artificial vacuum, it is there considered to terminate. This may appear an amazing thickness, but it dwindles to a small ring, when compared with the earth's diameter, of which it forms only the 1-177th part. In this diametric section, in which

the Earth is represented as 36 inches in diameter, the proportionate thickness of the atmosphere is no more than the one-fifth of an inch.

The mean *density* of the earth, as determined by pendulum experiments, is nearly six times that of water, or 5·66, according to the experiments of the late distinguished philosopher, Mr. Francis Bailey; but the average density or specific gravity of the rocky masses composing the crust of the globe, is less than three times that of water—about 2·5 to 2·8. The density of the Earth, therefore, is much less than that of all the common metals, and falls between the specific gravity of Tellurium (6·1), and Titanium (5·3). Hence we have reason to believe, that while the substances composing the mass of the globe are heavier than those which form the surface, they are considerably lighter than tin, iron, lead, and other common metals. It was this result, combined with the theory that the density of bodies should increase as we approach the centre of the earth, which led the celebrated philosopher, Professor Leslie, to suppose that the globe must be a hollow sphere, and that we are living upon a shell, the thickness of which bears only a very slight proportion to the earth's diameter!

The most careful researches tend to show that the *temperature* of the surface of our globe, including that of the air, earth, and sea, depends exclusively upon the quantity of heat transmitted to it from the sun. The heat thus received is again lost, partly by radiation into space, and partly by conduction downwards through the superficial strata. The chief loss undoubtedly takes place by radiation; and it is by the amount of this, that we learn the temperature of the medium (space) in which our globe is floating. The lowest natural temperature hitherto observed, on the earth, was determined by Ermann at Yakutsk, the capital of Eastern Siberia. In January, 1829, the thermometer was observed by him to fall to 72° below the zero of Fahrenheit, or 104° below freezing. Now, on the theory of reciprocal radiation, space must be at or below this temperature; and were there not an annual compensation by the heat derived from the sun, the surface of the earth, notwithstanding the existence of subterranean heat, would be speedily cooled to a temperature which would render it entirely

uninhabitable. Some portion of the heat received by the earth from the sun, is conducted downwards by the strata; but its progress is arrested within a very short distance of the surface; for the extent to which solar influence penetrates, is exceedingly small. This is determined by burying thermometers in the earth, or fixing them at different depths in mines and other excavations. The experiments hitherto made, lead to the following interesting results. Diurnal variations of temperature are not perceived beyond two or three feet. Variations depending on the months or seasons, extend somewhat lower; and annual variations are entirely lost at a depth of from 60 to 100 feet, varying slightly in different localities. The maximum depth at which the changes in the thermometer are perceptible, amounts to only 1-400,000th part of the earth's diameter! Upon the alternate heating and cooling of this film, which does not exceed the nine-millionths of an inch in a globe of three feet in diameter, depend all the vicissitudes of temperature in climates, seasons, and cycles of years.

In the diametric section already referred to, in which the diameter of the earth is represented as thirty-six inches, the proportionate depth to which the heating power extends, is therefore not more than the nine-millionths of an inch!

The extent to which the strata become warmed by the sun, must depend,—1st, upon the directness with which the rays fall,—hence it is greater in the tropics than in temperate regions, and greater in summer than in winter; 2d, upon the conducting power of the strata, which is subject to great variation. It is, however, obvious that the *depth* to which this solar influence extends, may be determined by the thermometer. If below the surface of the earth, we can find a stratum in which, after a long series of careful observations made at all seasons of the year, and at all periods of the day and night, this instrument remains stationary, it is certain that we have reached a depth beyond which the power of the sun cannot extend. Such a stratum has been found, and it is called the stratum of INVARIABLE TEMPERATURE. Its position has been determined in some instances experimentally, in others theoretically.

The most accurate observations on the position of this invariable stratum in these latitudes have been made at Paris. In

July, 1783, a very delicate thermometer was placed by Lavoisier in an excavation beneath the Observatory of Paris, at a depth of ninety feet below the surface of the soil. This thermometer was so sensitive to changes of temperature, as to allow of the measurement of what would be equivalent to the one-hundredth part of a degree on Fahrenheit's scale. From the observations of Cassini, Bouvard, and others, extending over a period of *fifty years*, this thermometer has remained stationary at a point corresponding to 53° F., which is about a degree and a half above the mean temperature of the climate of Paris. On one occasion only, within the last seventeen years, it was observed to rise about a *quarter of a degree!* This was attributed to the effect of currents of air resulting from some excavations being made in the quarries adjoining the Observatory. Hence in Paris the position of the invariable stratum of temperature is fixed at from 80 to 100 feet below the surface. In no other place in the world has so extensive a series of observations been made: but from a few data, and from theoretical considerations, the stratum has been considered by Humboldt to exist throughout Europe, between the parallels of 48° and 52°, at from 55 to 60 feet. Professor Thomson makes its depth below the surface in England to be from 30 to 60 feet; and the experiments performed by Mr. Fox on the mines of Cornwall, render it probable that in that county, it is situated at from 60 to 75 feet.

One test which has been proposed for the invariable stratum, is, that its temperature should correspond to, or differ but little from, the mean temperature of the climate in which the observations are made. On this principle, Boussingault fixed its position in the tropics at one-third of a metre, or rather more than a foot below the surface of the soil: but the recent experiments of Captain Newbold have shown that this is an error; the *diurnal* variation at this depth amounting to as much as 2°·75 F. Captain Newbold found the thermometer to remain stationary, in a shady locality, at about four feet; *i. e.* at that depth the temperature corresponded to the mean of the atmosphere. In high latitudes, the position of the invariable stratum has not been accurately determined. The only correct obser-

vations yet made are those of Ermann and Baer, at Yakutsk, in Eastern Siberia. M. Baer ascertained that in this desolate region the ground is thawed, during the short summer, only to the depth of three feet; below this, at all periods of the year, there is a band of ice, or frozen soil, which has been perforated to the depth of 382 feet, but without entirely traversing it. The solar influence, therefore, scarcely extends, in the course of seasons, beyond three feet from the surface.

The invariable stratum must not be considered as a *line*, but rather as a *zone*, varying from 2 to 40 or 50 feet in thickness. Its course below the surface is probably that of a *curve*, its depth being affected by many local circumstances—such as the nature of the strata, the situation of the place, whether it be on a plain, on a mountain, or in a valley—in the midst of a vast continent, or in the vicinity of seas, lakes, and rivers. Whatever affects the mean temperature of a place, must affect its position. The influence of the strata in altering the position of this zone was observed by Captain Newbold in the tropics. He found a constant temperature to exist at four feet depth from the surface in *clayey* soils, but in order to obtain it in light *sandy* soils, it was necessary to go much deeper.

Professor Forbes has undertaken some interesting experiments on the conducting power of the strata in the neighbourhood of Edinburgh, but numerous observations are required in various latitudes before any satisfactory conclusions can be drawn on the subject: neither has the proportion between the quantity of solar heat radiated and that conducted downwards by the earth been correctly ascertained. One fact is certain, that when the earth is heated by the sun, that portion of heat which is not radiated or carried off by the evaporation of water from the soil—a condition which must cause the dissipation of an enormous quantity—is slowly transmitted to the interior; but when the quantity radiated exceeds the quantity received by the earth, as during the night or in the winter season, then a portion of that which has been conducted downwards, must again return to the surface and be dissipated. Hence there will be a succession of waves of caloric descending or ascending, according to the temperature of the earth's surface. The quantity that

descends must be small, and it will finally meet the ascending currents of caloric proceeding from the interior of the globe, whereby an equilibrium will be established.

INTERNAL HEAT.

We now, however, arrive at the important fact, that if a thermometer be carried *below* this invariable stratum, it immediately begins to rise, and in a degree subject to some local exceptions, proportioned to the depth to which it is carried. It is obvious that this increase of temperature cannot be due to solar influence.—1. Because the existence of a zone of invariable temperature shows that the power of the sun must be limited to that portion of the earth's crust which is above it.—2. Because, if the interior heat of the mass of the earth were due to external or solar influence alone, the thermometer should fall just in proportion as we descend below the invariable stratum. But the reverse of this is the fact, as we may presently be able to establish from the results of accurate observations. Hence we are irresistibly led to this conclusion—that in going below the invariable stratum, we are approaching some great source of heat, which must be situated within the interior of our globe.

It is not to be supposed, however, that the same increase is observed at equal depths in all places. As there are isothermal lines over the surface, so there are isogeothermal lines below it. Thus it was observed that among five of the principal mines of Cornwall, in three the air had a temperature of 64° at 500 feet below the surface; but in two of them it was necessary to go to the depth of about 700 feet, in order to obtain this temperature. An *isogeothermal* line is, therefore, a curve of equal temperature below the invariable stratum, and when widely distant places are taken, considerable deviations are found. Thus, in the latitude of Paris, it was ascertained, by sinking the well of Grenelle, that in order to obtain a temperature of 72°, it was necessary to go to the depth of thirteen hundred feet. In the Monkwearmouth mine near Sunderland, the same temperature was obtained only at fifteen hundred

feet; in Joseph's well, at Cairo, at the depth of two hundred and ten feet—in the tropics this temperature exists still nearer the surface: in Siberia it is scarcely possible to assign the depth at which this temperature would be obtained, since at four hundred feet the temperature of the strata begins to rise only above the freezing point. Making all due allowance for elevation and depression above the sea level, it is obvious that there must be great irregularity in these isogeothermal lines, or lines of equal terrestrial heat. In some instances there is a near approximation over great distances. Thus the water of an Artesian well at Vienna, 200 feet deep, has a temperature of 55°; while the water of another, at Hanwell, in Middlesex, at the depth of 290 feet, has the same temperature. These places are about a thousand miles apart. The water of the well of Grenelle, in Paris, at 1794 feet in depth, has a temperature of 82°; that of Mondorf, which is 2,202 feet deep, has a temperature of 93°; therefore increasing in a proportion which might be anticipated from the difference in the depth.

The existence of SUBTERRANEAN HEAT is an old hypothesis. Cosmogonists have imagined that the whole earth was once in a state of fusion; and that, as a result of attraction and rapid rotation on its polar axis, it assumed in its semiliquid condition the form of an oblate spheroid. The existence of vitrified rocks scattered over a large extent of the earth's surface, with the well-known phenomena of volcanic action, lent considerable support to this opinion. These hypotheses must not, however, detain us, as our object is rather to shew that to which reasoning from well-ascertained facts will lead, than to criticise schemes which pretend to explain the grand phenomena of creation.

There are several *sources of proof* upon which the existence of a high temperature within the interior of the earth is made to depend:—

1. The progressive rise of the thermometer as we descend into mines, and other deep excavations, below the level of the sea.
2. The high temperature of the water which issues from Artesian wells carried to a great depth.

3. The high temperature of natural thermal baths and springs.
4. The phenomena which accompany volcanic eruptions and earthquakes.

TEMPERATURE OF MINES.

The thermometer has been exposed to the air, earth, and water, at the bottom of some of the deepest mines in various parts of the world. An increase of temperature has been invariably observed, although not always marked by a uniform rate of progression. Our object, however, is at present rather to establish the general fact, than to account for the anomaly

Some of the earliest and most accurate experiments in this country were made by Dr. Forbes on the Cornish mines, and were published by him in the Transactions of the Royal Geological Society of Cornwall for 1822. His results were obtained from an examination of the air and water in six of the principal Cornish mines. The general conclusion at which he arrived was, that while the mean temperature of the climate of Cornwall was about 51°, the thermometer stood, at the bottom of the deepest Cornish mines, at about 80°; that the temperature was 70° at a less depth than 1000 feet, and that it was 5° or 6° above the mean temperature of the climate at no greater depth than from 200 to 400 feet. He also observed another interesting fact, that in the progressive deepening of a mine, the temperature went on gradually increasing.

The average rate of increase in temperature, reckoning from the surface, was about 1° for a descent of every 50 or 60 feet. The ratio of increase would be greater if the depth were calculated to begin from the invariable stratum; but as the position of this, in the absence of numerons observations, must be in many places more or less conjectural, it is perhaps safer to calculate the increase from the surface, where the mines are on or about the same sea-level. In all these calculations, therefore, the increase of temperature is really higher than the tables represent; for the thermometer does not begin to show a pro-

gressive rise until we have passed below 50, 60, or 80 feet at the least.

Since Dr. Forbes's experiments were performed, in 1819-1822, the Cornish mines have been considerably deepened, and numerous observations have been made by Mr. Fox, principally, in the years 1837-1839 Taking the deepest mines, Mr. Fox found that the thermometer rose, on the average, 1° for every 49·6 feet. Similar experiments made by Captain Oats gave a result of an inerease of 1° for every 48 feet of descent from the surface. Hence the results of Dr. Forbes's experiments were corroborated, twenty years after their performance, by those of Mr. Fox and Captain Oats: thus leading to the important conclusion, that the ratio of increase in descending the Cornish mines continued very uniform for that long period. The transmission of heat from the interior of the globe does not, therefore, appear to be subjeet to any great disturbing influences; and we have in this an additional proof, that it must be wholly independent of solar influenee. The fluctuations of temperature are great above the invariable stratum, but in the same loeality they are insignificant below it. At the bottom of one of the deepest mines of Cornwall, Mr. Fox found that the temperature of the rock of a gallery, observed for a period of eighteen months, eontinued uniformly at 76°.

The ratio of increase given in the table is only an average. In one Cornish mine, 1200 feet deep, it was 1° in 43 feet; in another, not far distant, 1° in 77 feet. These differences are probably due to the different degrees of conduetibility in the rocks and strata; for experiments lead to the conclusion, that in the same mine there is little or no fluctuation.

It is not surprising that a difference in the results should be observed in different strata. In the salt mines of Cheshire, which are less than 500 feet in depth, the increase is 1° for 70 feet. The water of the coal mines of the North of England has been found to give results more nearly approaching to those obtained in Cornwall.

One of the deepest mines in England is that of Monkwearmouth in Durham. Some years sinee, when the depth of this

pit was 1584 feet, and the mean temperature of the air at the surface was 47°·6, a thermometer at the bottom of the shaft, in coal, indicated 72°·6, or 25° increase of temperature above that of the surface. This gives a progressive increase in descending of 1° for every 60 feet.

Observations made in the mines of France and Germany have led to nearly similar results. Thus it is found that in descending below the invariable stratum, the thermometer gradually rises, and that for the same locality the ratio of progressive increase remains uniformly the same over a long period of years. According to Pouillet, the average rate of increase in these mines is 1° for from 45 to 50 feet of descent.

The mines of Mexico are well known to have a very high temperature. The deepest of these (Valenciana) at Guanaxuato is 1770 feet: the air at the bottom has a temperature of 99°. These mines, however, can hardly be said to penetrate the crust of the earth, for the lowest level of the deepest is nearly 5,000 feet above the surface level of our Cornish mines.

In closing the evidence derivable from the examination of the temperature of mines, it will be seen that the total rise of temperature is small, but at the same time certain, and as far as we can judge, universal. Thus even at Yakutsk in Siberia, Ermann and Baer found that the thermometer rose as the *frozen* soil was penetrated. At three feet from the surface the thermometer stood at 18°; at 210 feet, at 27°; and at 382 feet, at 31°. There was, therefore, a progressive rise to the freezing point. Probably at 1000 feet below this, the temperature would be found as high as in similar excavations in Europe. In no mine or excavation yet explored has the thermometer been found to fall in proportion to the depth, after the invariable stratum had been once passed.

The very slight increase observed in deep mines,—the temperature never, I believe, in any case exceeding 99°, has given rise to an opinion that it might be due to the respiration of animals, the combustion of candles, and the heat evolved in the general working of the mine. At first view this explanation appears plausible; but it will be seen from the following facts, that it is quite inadmissible. Thus it does not explain why there is a

progressive increase in descending, why the hottest part of the mine is always the deepest, or why, when the thermometer is plunged three or four feet into the soil below the lowest level, it still continues to rise. Again, this hypothesis would not account for the rise of temperature in descending into mines and shafts which have been long abandoned; or for the steady preservation of temperature, for eighteen months together, at certain levels, according to the depth. Perhaps you will think it unnecessary that I should adduce further reasons for the rejection of this hypothesis; but I will here quote one fact, mentioned by Mr. Phillips in his excellent Treatise on Geology, which appears to me to remove all doubt, if any could exist, with respect to the source of heat. I have already referred to the Monkwearmouth mine as being 1584 feet deep; a few days after this immense depth had been reached, before any horses had entered the mine, and while but few workmen were employed in other parts of it, the temperature of the lowest stratum of the air was taken, and the thermometer then showed an increase of 25° above that of the surface. It is further worthy of remark, that the air, which is supposed by this hypothesis to become heated artificially, was, at the time the observations were made, many degrees *cooler* than the surrounding coal-strata and rocks, and it grew hotter only as these exerted an influence upon it. Another hypothesis has been suggested, namely, that the slight increase of temperature may be due to chemical decomposition going on in the strata themselves. But this explanation will not suffice. If it even appeared satisfactory with respect to the coal-strata, from the presence of pyrites, and their well-known tendency to undergo chemical changes, it would not account for a progressive rise of temperature in granite, slate, salt, or ice, as observed in the frozen soil of Siberia. In short, no theory will consistently account for the fact, but that which admits the existence of subterranean heat.

TEMPERATURE OF WATER IN ARTESIAN WELLS.

The temperature of water as it flows below the surface of the earth, must of course be regulated by that of the strata with

which it is contact. In common wells, sunk in this latitude to a depth of 50, 60, or 100 feet, the temperature of the water is generally found to correspond with the mean temperature of the climate. The water in the chalk wells at this depth around London, has a temperature of about 51°; at Brighton, varying from 50° to 52°; at Tunbridge, 50°; thus nearly corresponding to the mean temperature of the climate. It has been found that the water in the wells at New York, at a depth below 40 feet, has a temperature of from 54° to 56°. The mean temperature of New York is nearly 55°.

This uniformity of temperature at slight depths is explained by the water being in contact with, or near to, the invariable stratum. Thus when we cannot descend a shaft, and examine the air by a thermometer, we have in temperate latitudes a method of determining the position of the stratum, and the mean temperature of a climate, by observing at what depth the water contained in wells ceases to mark any annual fluctuations.

We now come to the fact that water, which issues from below the invariable stratum, will present a high temperature in proportion to its depth. In the springs which abound in mines, and in Artesian wells, this depth admits of measurement; and the degree to which the thermometer rises for so many feet of descent, may therefore be determined.

Dr. Forbes found in his experiments that the temperature of water in the Cornish mines gradually rose with the depth, the ratio of increase being 1° in from 45 to 50 feet. Mr. Fox ascertained some years since that from the Poldice mine at 1000 feet in depth, the average quantity of water pumped daily amounted to two millions of gallons, varying in temperature from 90° to 100°; *i. e.* from 40° to 50° above the mean of the climate. This fact alone would show that if the heat of the air in mines was owing to the respiration and combustion, the hypothesis would not suffice to account for the very high temperature of the enormous quantity of water thus daily brought to the surface.

Artesian Wells present numerous interesting facts. I have already referred to those at Vienna in Austria, and at Hanwell

in Middlesex. One of the most remarkable of these is that of Grenelle in Paris, the depth of the water from the surface is 1794 English feet, and its temperature is 82°. The temperature of the water was found to rise 9° in the last 500 feet; that is to say, about 1° in 55 feet. In another well, that of Mondorf, the deepest in the world (2202 feet), the temperature of the water is 93°, indicating an increase of 1° in 54 feet.

The results obtained by the examination of these Artesian waters, in various parts of England and the continent, corroborate those derived from an examination of the solid strata of the earth. Local variations of course exist, but in wells extending to below 300 or 400 feet in depth, the average ratio of increase is about 1° for 46 feet in depth.

THERMAL SPRINGS.

These springs may be regarded as natural *Artesian wells*, rising from a depth in proportion to their high temperature, if we except those which are in close proximity to volcanoes. Some of these springs have a temperature approaching the boiling heat of water, but they vary for the most part from 60° to 180°. The hottest spring in Great Britain is that of Bath, 117°; in Ireland, that of Mallow, 72°. Sometimes it happens that cold springs are close to them; but then they undoubtedly proceed from very different depths. These singular anomalies are found in the Feejee Islands in the Pacific, and also at Baden Baden. In Great Britain, hot springs are observed to issue through points of displacement in the strata; and Professor Forbes remarked that the numerous hot springs of the Pyrenees, generally proceeded from the junction of stratified with unstratified rocks. In short, these springs are found to appear in those localities, where there exist natural cracks or fissures in the strata.

It is not so easy to say by what force these thermal waters are brought to the surface of the earth. The theory of hydrostatic equilibrium will hardly explain the phenomenon; for in some instances, the springs appear to issue far above the level

of any source of water which, by its percolation through the earth, would at all account for the uninterrupted flow of these springs through the long course of ages. The temperature of the Lenker Spring in the Canton of the Valais in Switzerland, is 144°; and it issues from the earth at an elevation of 5000 feet above the level of the sea. This is near the region of eternal snow, and I am not aware that there is any source of water above the level of this spring, adequate to its supply on the hydrostatic hypothesis.

The water of these thermal springs does not differ in any remarkable degree from that of other springs. According to Humboldt, the hottest are the purest—the waters contain less saline matter—but in general they are strongly impregnated with gases, apparently condensed under great pressure. Although they issue from depths to which man has never been able to penetrate, they contain the same saline constituents as the cold mineral waters. Some are sulphureous, others chalybeate—the nature of their constituents depending on the chemical composition of the strata through which they rise. The probability is, that the water is nothing more than rain water which has percolated to a great depth, and has thereby acquired a high temperature from contact with the strata.

It is a striking fact, and one indicating their close connection with the internal heat of the globe, that these springs are liable to be affected by volcanic eruptions and earthquakes over large tracts of the earth. Those situated near volcanoes either cease flowing or undergo some change of temperature at the time of an eruption. Professor Phillips mentions that in 1755, during the occurrence of the great Lisbon earthquake, the temperature of the thermal spring called the Source de la Reine, at Bagnères de Luchon in the Pyrenees, was raised 75°. The temperature of this spring is now 152°. This fact appears to furnish a remarkable proof of a subterranean connection existing under the whole peninsula of Spain, from the Pyrenees to the Atlantic, a distance of 600 miles. But, according to Neumann, the influence of this earthquake on thermal springs was perceived at a still greater distance; for while it continued,

the Sprudel Spring at Carlsbad, in Bohemia, ceased to flow. The influence was here extended over a distance of 1400 miles.

Thermal springs are found in all parts of the world—in Greenland, Iceland, and in the equatorial regions—in the midst of continents, and in the scattered islands of the Pacific Ocean. The hottest, which either reach the boiling point of water, or have a temperature very near it, are in South America and New Zealand. The hottest springs are not necessarily in the immediate vicinity of volcanoes. Thus Humboldt observes, that the Trincheras and Comangillas springs, in South America, issue from granite, and have a temperature varying from 194° to 207°; while those on the volcanoes of the Andes, vary in temperature from 97° to 131°. One remarkable fact must be here noticed: Humboldt observed in 1800, that the Trincheras Spring had a temperature of 194°. Boussingault examined the same spring in 1823, and found it to have a temperature of 207°: it had thus risen 13° in 23 years. There is a thermal spring in Greenland, that of Ournartok, which has a temperature of 104°, and the Geyser Spring of Iceland is too well known to require description.

The quantity of water which issues from thermal springs is very constant throughout the year. This fact, together with their high temperature, shows that their heat must be entirely independent of atmospheric and solar influence. They may be regarded, indeed, as natural thermometers on a large scale, serving to indicate the heat of the interior of the globe from the equator to the poles. Some of them have been flowing uninterruptedly for upwards of a thousand years; and, so far as we can judge from historical records, without undergoing any marked change of temperature. They were described as hot springs, and used as hot baths by the Romans 1700 years ago. As an illustration, I may mention to you Nero's Baths, on the coast near Naples:—the water has a temperature of 121°. According to Humboldt, some are now flowing in Greece, which are mentioned by Herodotus and Strabo, and which were used for baths by the Greeks before the time of the Mithridatic war.

The continued flow of these thermal springs, in countries where there are extinct volcanoes, appears to indicate that the

effects of subterranean heat are merely suspended; and that the extinct may at any time become suddenly converted into an active volcano. Thus, in the interesting province of Auvergne in Central France, there are several hot springs, one of which has a temperature as high as 176°: others, such as those of Mont d'Or and Vichy, a temperature of about 113°. The view of this district, from the summit of the Puy de Dome, includes no less than 180 volcanic craters; and the last record of any eruption in this region extends as far back as the year 458. These volcanoes, which have covered a large portion of central France with lava and ashes, have been, therefore, extinct fourteen centuries. They are, indeed, now what Vesuvius was in the seventieth year of the Christian era, immediately prior to the eruption which destroyed Herculaneum and Pompeii. We are in the habit of speaking of them as extinct, but the uninterrupted flow of the thermal springs around them, appears to indicate that the great cause of their former activity is only latent.

It has been supposed that the *depth* from which thermal springs issue, might be calculated from their temperature; fifty feet being allowed for every degree above the mean temperature of the climate. Thus the water at the bottom of the Dalcoath mine in Cornwall has a temperature of 84°, *i. e.* 33° above the mean temperature of the climate. This is the temperature of the thermal spring at Buxton,—hence the depth of the Buxton spring has been assumed to be 1500 feet below the surface. The temperature of the hottest of the Bath springs is 117°, *i. e.* 67° higher than the mean temperature of the place. The depth of the basin of the Bath water has been, therefore, calculated at 3350 feet, or nearly three quarters of a mile. On the same principle, Humboldt has estimated the depth of the Comangillas spring in South America at 6700 feet.

There is one obvious objection to this mode of calculation, namely, that it assumes a regular increase for great depths, from average results obtained only on comparatively small depths.

The conclusions which it appears to me we are entitled to draw from the facts hitherto obtained respecting thermal springs,

are—1st, that their temperature is wholly independent of all local circumstances; were it otherwise, it would be impossible to account for their preserving a high temperature for more than a thousand years. 2d, that the temperature of these springs is due to subterranean heat. 3d, that there are no accurate means whereby we can determine the depth from which they issue.

VOLCANIC ERUPTIONS AND EARTHQUAKES.

The last great proof of the existence of subterranean heat is furnished to us in the phenomena which attend volcanic eruptions. Volcanoes are spread over the whole of the earth. They appear to be fiery vents in the superfical crust, through which vast masses of igneous rocks are raised from the interior and poured out upon the surface of the globe. At the present time it is calculated that there are 193 volcanoes in a state of activity. Of these, there are 58 on the islands of Asia, and 87 on the continent of America. They rise up through the ocean as well as on land, although in general they are either insular or littoral,—in the midst of eternal ice, as Mount Erebus, in latitude 78° South, which is 12400 feet in elevation; or under the equator, as Cotopaxi, which reaches nearly 19000 feet above the sea-level. From the similarity of the phenomena which accompany their eruptions, and the nature of the substances ejected, it is evident that they must proceed from one common source; and there is every reason to believe that they have some general connection below the superfical crust of the globe. In short, they appear to demonstrate, within the interior, the existence of a full red heat, extending from the equator to the poles.

Having thus examined the various sources of evidence respecting the existence of subterranean heat, we find that, from the exploration of mines and Artesian wells, we obtain proof of an increase of temperature amounting to about 100°; of thermal springs,—a temperature as high as that of boiling water; and

from the perfectly fused nature of the substances ejected from volcanoes,—a temperature equal to a full red heat of more than a thousand degrees.

These phenomena appear to be quite inexplicable, except upon the supposition, that at some depth below the surface of our planet there is a vast source of heat; and it may, therefore, be as well to consider, to what depth we have really attained in the penetration of this crust, and how far we are justified in adopting certain theories, which have been brought forward in relation to this interesting subject.

The depth to which we have actually penetrated below the level of the sea is barely *half a mile; i.e.* in the deepest mine, not more than 1-16,000th part of the earth's diameter!—We have here a table of some of the deepest mines and excavations in the world. In this plan, or horizontal section, on a vertical scale of two miles to an inch, the shafts of mines become just visible as perforations in the strata. In a globe three feet in diameter they cannot appear,—even as points. The Valenciana mine, in Mexico, is 6,000 feet above the sea-level—the deepest mine in Cornwall is 1230 below it, and, therefore, 7,230 feet nearer to the centre of the globe. The Monkwearmouth shaft, in Durham, is 1500 feet below the sea-level; the Artesian well of Grenelle extends to a similar depth; and that of Mondorf is somewhat deeper. The deepest mines of Saxony do not extend half a mile below the mean sea-level:—the line from which we must consider the earth's crust to be actually penetrated. It is calculated, from the dip of certain stratified rocks, that the mountain limestone descends to 12,000 feet below the level of the sea; and the coal strata at Duttweiler, near Bettingen, to 20,656 feet below; *i. e.* rather less than four miles. Admitting these views to be correct, this gives us a knowledge of the probable composition, but not of the temperature, of the strata for about *one two-thousandth* part of the earth's diameter. If the same rate of progression for increase of temperature were assumed to exist in these strata, as that observed in smaller depths, it would not exceed 420° even at four miles. This is about the melting point of tin—one of the most fusible of metals.

The fact, however, remains:—we derive from observation the absolute knowledge of a slight increase of temperature for no more than the 1-16,000th part of the diameter of the earth! From imperfect data of this kind, it is clearly out of our power to generalize upon the progressive rate of increase, in proceeding from the surface to the centre, or to form any satisfactory opinion of the composition and temperature of the great mass of the globe.

Nevertheless there has been no deficiency of bold speculations. Buffon looked upon the earth and all the planets, as balls originally melted, and cooling from a state of fusion. He considered that the heat of climates on the globe was due to a portion of this high temperature still remaining within, and that we are gradually cooling down to the intense cold of space. So impressed was he with this notion, that, by a series of calculations, more ingenious than sound, he came to the conclusion that it had required rather more than 74,000 years for the mass of the earth to cool down to its present temperature; and that the heat of the earth would be entirely dissipated in 93,000 years. Following out these bold calculations, he constructed a table of the absolute duration of the different planets, or the time which they will respectively take to become entirely cold and uninhabitable. Among other strange conclusions at which Buffon arrived, we find it stated that Saturn was to be deprived of his ring 10,000 years before the planet itself had become cooled down to the temperature of space!

Halley, the celebrated astronomer, believed that the earth was a hollow sphere, and that the internal cavity was subdivided into spaces, like the stories of a house. Professor Leslie adopted a similar opinion, formed from the low density of the mass of the earth. He believed the globe to be cavernous, the interior being filled with elemental heat or light, in its most concentrated state, shining with the most intense refulgence!

Another philosopher took up the view that the hollow sphere was tenanted by plants and animals: that there was one unchangeable temperature reigning within, and that the cavernous atmosphere was self-luminous, by the effect of condensation. He had further satisfied himself that there was a large aperture

favourable for a descent into the interior, in the 82d parallel of North latitude; and he went so far as to send an invitation to Baron Humboldt and the late Sir Humphry Davy, to accompany him on a subterranean expedition. They, however, prudently declined the invitation!

Other philosophers have occupied themselves in endeavouring to determine the degree of heat which exists within the interior, and some of them have arrived at what appear to be the most alarming conclusions. Proceeding on the assumption that the heat increases one degree for every fifty feet of depth, even to the centre of the globe, at the distance of 4,000 miles from the surface, they have ascertained that this is equal to an increase of 116° of temperature for each mile, and would amount to about 3,500° at a depth of only thirty miles. This temperature, it may be observed, is sufficient to melt cast iron, and to fuse into a pasty liquid all the solid constituents of the globe. It is upon this theory that the foci of volcanoes have been placed at a depth of from 30 to 40 miles below the earth's surface.

Before proceeding farther, it may be as well to state, that the highest temperature known to us, by even the approximative measurement of the pyrometer, does not probably exceed 3000° of Fahrenheit's thermometer: the highest temperature which has yet been actually measured by this instrument is 2,786°. The melting point of granite, according to Mitscherlich, is 2,372°; and this temperature would exist, on the above hypothesis, at 21 miles from the surface, which is only the one four-hundredth part of the earth's diameter. One philosopher, in carrying out his calculation on the progressive rate of increase already stated, has come to the conclusion, that the temperature of the centre of the globe must be no less than 418,000°. You will reasonably inquire, how such a calculation can be made from data furnished by an examination of only *one eight-thousandth part* of the distance? It is scarcely necessary for me to say, that the data are altogether insufficient for the purpose. Besides, one very material fact has been forgotten in these calculations; namely, that when the melting point for all solid matter has been once reached below the surface, there can be no farther progressive increase of temperature in

descending; for the heat will then be distributed uniformly and rapidly by circulation, as it is in all liquids and gases. Let us, for the sake of illustration, regard the earth as a thick glass globe, into which a quantity of hot water has been poured. The outer and inner surfaces of the shell of glass might have very different temperatures, but the liquid contents would speedily acquire and retain the same degree of heat throughout. To imagine, therefore, that a higher temperature than that required for fusion, exists within the interior of the earth, is contrary to all which experience has taught us respecting the distribution of heat in liquids.

M. Fourier, who devoted much attention to this subject, and whose researches have been well received by men of science, came to the following conclusions:—

1. That the heat which exists in the earth, below the invariable stratum, is the primitive heat which it received at the period of creation.
2. That this heat exists in a vast central nucleus, and begins to diminish in intensity at a certain distance from the centre, this diminution going on progressively to the invariable stratum.
3. That the temperature now observed will go on decreasing, until all the primitive heat of the earth is dissipated by radiation from the surface; but that it will require a very long series of ages to render its loss perceptible to our observations.
4. That the flow of primitive heat from the interior, and its escape from the surface of the earth, can exert no appreciable influence upon the mean temperature of the surface, nor upon those fluctuations observed during different seasons in the superficial strata. It would not make the difference of one fifty-fourth part of a degree in the surface-temperature. That even if the crust of the globe were of cast iron, and therefore an infinitely better conductor of heat than it is, it would require myriads of years for the subterranean heat to be transmitted to the surface from a depth of only 150 miles. The quantity lost by radiation

from the surface, he estimated to be infinitely less than the ten-thousandth part of a degree in a year, or one degree in 10,000 years. This loss, it is obvious, could neither affect climate-temperature, nor have any influence whatever on animal or vegetable life.

5. Climates and seasons depend entirely on the heat which is diffused through the superficial strata above the invariable stratum. This heat is derived exclusively from the sun. It accumulates at one period of the year, but is lost at another, so that there is in the end an exact compensation.

These conclusions were based—1. On the assumption that we have already attained an exact measurement of the ratio of increase of temperature in the 4000 miles of earth beneath us; and, 2d. That the exact rate at which the strata conduct caloric is determined. These postulates, it appears to me, cannot be conceded, and all that M. Fourier has really proved, is—1. That there is a great source of heat in the interior; and, 2d. That we have no means of determining that this undergoes any periodical loss. He speaks of a central nucleus of heat, but he appears to forget that, on his own showing, there must be beneath us a sphere of *liquid* matter of uniform temperature, and probably 3,970 miles in thickness.

To whatever conclusion we may come respecting this question, it appears certain, so far as our present means of observation will enable us to judge, that all the phenomena connected with temperature on the surface of the earth, are explicable on the supposition that they are entirely due to the balance which exists between the heat received from the sun and that which is radiated into space or conducted downwards into the strata. This is proved by the fact, that daily and monthly changes of temperature correspond *cæteris paribus* with the position of the sun: and the mean annual temperature, making due allowance for local circumstances, is dependent on the quantity of solar heat received. Probably a century of accurate observations, made with the thermometer, would show that our globe had become neither perceptibly hotter nor colder. Some have asserted that

the climate of Europe has become colder, while others have thought that it has become hotter during the last 2,000 years. Had the thermometer been known to the Romans, and registers kept, we might now have before us the elements for solving this interesting question; but in the absence of correct data, the two conflicting opinions may perhaps be fairly regarded as neutralizing each other. Signor Libri, of Florence, has shown, by comparing our modern thermometers with one of those early instruments constructed by the Academia del Cimento, in 1667, that no change whatever has taken place in the climate of that part of Italy during the last 200 years. According to Arago, the temperature of the earth cannot have varied so much as the one three-hundredth part of a degree of Fahrenheit since the days of Hipparchus, a period of about 2,000 years, or there would have been a perceptible change in the length of the day. This view is founded on the assumption, that a heated spherical solid contracts in cooling, and that by a diminution in the bulk of the earth, there would be a decrease in the length of the polar and equatorial axes, and consequently a measurable difference in its period of revolution. The contracting power of the earth in cooling, is, for the purpose of this calculation, assumed to be equal to that of glass. This principle is correct to a certain extent, but some recent observations, made on the cooling of spheroidal masses from a state of fusion, show that so soon as an external coherent crust is once formed, there is no longer a contraction in bulk, but a vacuum actually occurs in the interior of the sphere.

TEMPERATURE OF THE SEA.

You will probably be desirous of knowing how far the observations made on the earth, are corroborated by those which have been made on the *deep sea*. Experiments here are less satisfactory, owing to the imperfection of our instruments, and their liability to be affected by unseen counteracting causes—such as the currents which sweep over the ocean,—the law of the diffusion of heat in liquids, and the great difference in the density of water by variations of temperature.

The average temperature of the deep sea water is found to vary from 34° to 44°. This is assuming that the lowest temperature marked by the index of the thermometer, was acquired in the deepest stratum to which the instrument descended. In one of these deep fathomings it is stated to have required more than an hour to draw up the lead; and if the instrument should, in thus being raised, pass through a colder current than that which existed below, the index would of course be affected, and lead to error in the observation.

Water, it is well known, acquires its maximum density at about 39°·39; and we find by observations hitherto made, that the temperature of the deep sea varies but little from the equator to the poles. It is not far removed from that which theory would lead us to expect. The temperature of the surface varies, however, considerably, for while it has been found to be about 27° in the Polar regions, it is commonly as high as 83° under the equator. The deep sea is thus proved to be much colder in low, and much hotter in high latitudes, than the surface of the ocean.

From observations actually made, it appears that the temperature of deep sea-water in the equatorial regions, varies from 40° to 44°; but the average is about 42°. At the equator, in the depth of 2400 feet, the water was found to have a temperature of 44°, while at the surface it was 83°. This gives an average *decrease* of one degree for every sixty feet. Captain Wauchope fathomed the Gulf of Guinea under the equator, at about a hundred miles from the coast, and found no bottom at the depth of 3918 feet. The temperature of the deep sea-water was 43°, that of the surface 79°,—this is a decrease of one degree for every 108 feet. From four other experiments, the same observer concludes that the temperature of the deep sea will be found to be about 40° all over the world.

In 1829, Captain Foster sounded the sea off Cape Horn to the depth of 5400 feet; the water had a temperature of 34°, that of the surface being 39°. This is a decrease of barely a degree in 1000 feet. Among the deepest soundings in the South Sea yet recorded, are those which were made by the officers of the late French and English expeditions. The

officers of the French ship, Venus, sounded the sea at about 1200 miles south-west of Cape Horn, and found no bottom at the depth of 12420 feet; *i.e* rather more than two miles. It seems that the brass case of the thermometograph was broken in this instance by the pressure to which it was submitted at this depth. On examining the index it was found to mark 36°. Captain James Ross is reported to have sounded the Atlantic Ocean, 900 miles west of St. Helena, to the depth of 25400 feet, employing for this purpose a leaden weight of 450 lbs. Another sounding was made about 300 miles west of the Cape of Good Hope, to the depth of 13,356 feet, but there is no account of the temperature in these cases. The Polar Sea, at the depth of 2300 feet, has been found to have a temperature of 38°.

The temperature of the water at the bottom of deep lakes does not materially vary from that of the deep sea. Saussure made a most complete examination of this subject on all the lakes of Switzerland. Two of the deepest of the Swiss lakes are those of Geneva and Lucerne. The surface water of the lake of Geneva, examined during a cold season, was 41°, and at the depth of 1000 feet, the water had a temperature of 42°. In the lake of Lucerne (650 feet), while the surface-temperature was 68°, that of the water at the bottom was 41°.5, presenting the greatest difference among all the observations. The highest temperature observed was at the bottom of the lake of Bienne, 44°—the depth being 235 feet. This has been found to be the temperature of sea water under the equator at the depth of 2400 feet. The lowest temperature observed in these lakes was in Lake Constance, at the depth of 400 feet—the temperature of the water being 40°. The extreme range of temperature in the water of these deep lakes was only about 4°, and this nearly corresponds to the range of temperature observed at great depths in the ocean, if we except the Polar Sea. The surface-temperature of lakes is of course subject to continual variations according to the seasons—that at the bottom, is but little affected.

These observations on the sea and on lakes furnish us, therefore, with no evidence whatever in support of the theory of the

interior heat of the globe. How is this to be explained?—1. We must consider that the temperature of the sea has been taken at no greater depth than 12420 feet. This is about two miles, or one four thousandth part of the earth's diameter. It is very probable that the sea is not less than five miles deep,—Captain Ross is stated to have fathomed the South Atlantic Ocean to nearly this depth, *i. e.* 25400 feet, without finding any bottom. Professor Whewell calculates the maximum depth of the sea at nine miles. One fact, however, is quite certain, that we have not yet reached any point where the warmth of the subjacent earthy strata would make itself perceptible in the great mass of the waters of the ocean. Two miles of depth in the earth would not give a higher temperature, on the rough method of calculating already alluded to, than 232°. Five miles would give only 580°. Nine miles would give a temperature of 1000°. It is probable, however, that the submarine earthy strata have a considerable thickness, and their non-conducting power would prevent the transmission of any great degree of heat through them. The quantity which passed would probably be small; and this, by the currents of the ocean, and the peculiar laws which regulate the distribution of heat in liquids, would not be rendered perceptible to the thermometer, when we regard the immense mass of water which exists on the globe,—the area of dry land being to that of water as 100 : 270. Thus, then, the difference between the temperature of the earth and the sea, is easily reconcilable with the theory already propounded, while at the same time the extensive diffusion of insular volcanoes affords a sufficient proof that the waters of the ocean, like the dry land, are placed above a bed of igneous matter,

The conclusions which the foregoing remarks appear to justify, are—

1. That at a certain depth below the surface of the earth, there is a source of heat which progressively affects the thermometer as we descend.
2. That this interior heat cannot be derived from the sun or from local chemical changes.

3. That it does not directly affect climates or seasons, or perceptibly influence the temperature of the surface of the earth, the depths of the ocean, or the atmosphere floating above them.
4. That the vicissitudes of climates, seasons and cycles of years, are due entirely to solar influence.
5. That this influence, even at a maximum, does not penetrate to a greater depth than the 1-400,000th part of the earth's diameter.
6. That although we have positive evidence of the existence of subterranean heat, we can neither measure its degree, nor, at present, determine its exact ratio of increase downwards into the interior.
7. That there is not the slightest evidence to show that the earth is gradually cooling from a high temperature, or that, within the last two thousand years, its temperature has undergone any increase or diminution.

When, or how, the globe acquired this interior heat, whether from within or without, it is not for man to inquire, nor is it ever likely to become a subject of legitimate physical research. We may talk of nebulæ and fire-mists, and imagine that we have determined the steps by which the great Creator proceeded to build up the planetary system, and to separate the land from the water in the globe which we inhabit; but these are the dreams of false philosophy,—which admit neither of proof nor disproof.

Great as is the power of human reason, there is assuredly a limit to its exercise. True knowledge teaches us that it is derogatory to the character of sound philosophy, either to devise schemes of creation, or to attempt to determine by what process, and through what agency, the Creator will ultimately bring about the destruction of the earth. There is nothing to shew that the course of the great phenomena of the universe is left to chance,—to what has been denominated a primordial necessity, or to an uncertain and uncontrolled balance of attractive and repulsive forces. It is easy to speak of laws, the phantoms of our own imaginations, and to forget causes;—it is easy to

construct hypotheses, and lose sight of the imperfection of the data upon which they are based ; but a proper consideration of the very limited extent of our knowledge of the earth, will teach us that we are not in a position to speculate upon its origin, its internal structure, or its duration.

Admitting that we are living upon the mere shell of a heated mass of matter, some thousands of miles in thickness, we have no evidence to shew that this is allowed to exert any influence except for beneficial purposes. Without this internal heat, that which is transmitted to us from the sun would be continually conducted downwards into the interior, and be lost. The invariable stratum, therefore, appears to act as a kind of barrier to the too rapid transmission of this solar heat, and thus preserves to the superficial strata that temperature which is necessary to the support of animal and vegetable existence. Hence that which some philosophers have been inclined to regard as a great element of destruction, may, in reality, be the means of our preservation.

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